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Full-scale experiments on bend of pressure pipeline using geogrid

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ABSTRACT: In a bend of pressure pipeline, thrust force is generated. Commonly concrete block is set up on the bend in order to resist the thrust force. However, such heavy concrete block becomes a weak point during earthquake. Therefore a lightweight thrust restraint using geogrids and an anchor plate was suggested in previous study. In the present study, full-scale experiments were conducted using a pipeline (ϕ300) to verify the effect for the proposed method in actual size. As the results, the lateral movement of bend in case of the proposed method was reduced in comparison with a bend without the restraint. In addition it was clarified that the effect was depended on the stiffness and the length of geosynthetics.

1 INTRODUCTION

In a bend of pressure pipeline, thrust force is generated depending on the pressure level and the angle of the bend. Commonly a concrete block is placed on the pipe bend in order to resist the thrust force (M.A.F.E., 1988). However it was reported that thrust block on the bend caused damage of pipeline during earthquake since it moved largely due to inertia (Mohri et al., 1995). In addition, it can be expected that such heavy concrete block induces a differential settlement in pipeline on soft ground.

For these issues, new lightweight thrust restraint with geogrids and anchor plate was suggested by Kawabata et al. (2004). In the new method, geogrids and anchor plate were connected with the pipe bend as shown in Fig. 1. In addition, Kawabata et al. (2004) conducted the lateral loading tests using the model pipe (ϕ90) in order to clear the effect of the proposed thrust restraint. As the results, it was clarified that the lateral resistance in case of the proposed method increased by approximately 60% comparing with a model pipe without the restraint.

In this study, large-scale experiments were conducted using a pipeline (ϕ300) in order to clear the effect of the new method in actual size. In addition, the influences of the stiffness and the length of geogrid on the lateral resistance were discussed.

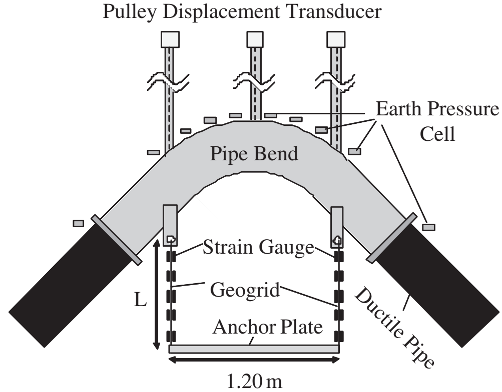

Figure 1. Test Setup.

2 EXPERIMENTAL PROGRAM

2.1 *Test procedure and materials*

Fig. 1 shows a test setup. A series of experiments described in this paper were carried out in a pit having the width of 5.4 m and the length of 8.4 m. In the pit, a bed having the thickness of 1 m was prepared and a pipeline having a diameter of 300 mm was set on the bed. The pipeline was consists of a bend (90°) and

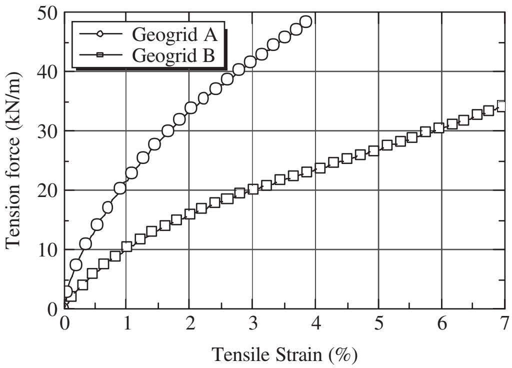

Figure 2. Results of tensile tests of geogrids.

4 short ductile iron pipes. After setting the pipeline, geogrids and an anchor plate were connected with the bend and were backfilled up to 0.6 m. Two types of geogrids (Geogrid A and Geogrid B) were used and results of tensile tests are indicated in Fig. 2. As shown Fig. 2, the stiffness of Geogrid A is larger than that of Geogrid B. In addition, a rigid steel plate (having the width of 1200 mm and the height of 300 mm) was used as the anchor plate. Ground was compacted by a vibration compactor every layer of the thickness of 0.15 m and the average dry density of ground was 1.75 g/cm^3. As backfill materials, screenings were used and its average particle size was 1.2 mm. The internal friction angle and the cohesion obtained from direct shear tests were about 38 degrees and 0 kPa respectively. After backfilling, internal water pressure was loaded using hydrostatic pump.

2.2 *Measurements*

In order to measure the lateral displacement of the bend, pulley type displacement transducers were used in front of the bend as shown in Fig. 1. In addition, loaded internal pressure was measured using a water pressure cell. Furthermore, in order to investigate the horizontal earth pressure acting on the bend, ten earth pressure cells were installed on the center level of the bend as shown in Fig. 1. In cases of using geogrid, strain gauges were used to measure tensile strain in geogrids in extensional and transverse direction.

2.3 *Cases of experiments*

Cases of experiments are indicated in Fig. 3. In Case-A, the pipe bend was buried without the thrust restraint and in Case-B, Case-C, Case-D and Case-E the pipe bend was connected to geogrids and an anchor plate. In Case-B and Case-C, high stiffness geogrids (Geogrid A in Fig. 2) were used and in Case-C and Case-E, low

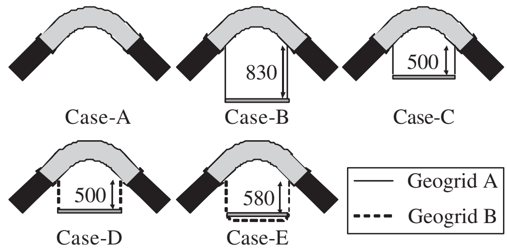

Figure 3. Cases of experiments.

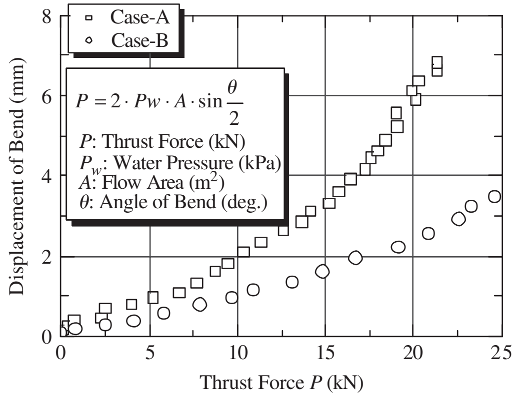

Figure 4. Relationships between thrust force and displacement of bend.

stiffness geogrids (Geogrid B) were used. In addition, geogrids were fixed on the side of the anchor plate in Case-B, Case-C and Case-D. On the other hand, geogrid was set as wrapping the ground and the anchor plate in Case-E as shown in Fig. 3.

3 TEST RESULTS AND DISCUSSION

3.1 *Lateral displacement of pipe bend subjected to thrust force*

Fig. 4 shows relationships between the thrust force and the lateral displacement in Case-A and Case-B. The thrust force P was calculated from internal water pressure, bending angle and cross-sectional area of bend.

From Fig. 4, it is found that the displacement of the bend increases with the thrust force in both cases. In addition, the displacement is about 6 mm for the thrust force of 20 kN in Case-A. On the other hand, in Case-B, the displacement is only 2.5 mm for thrust force of 20 kN. Therefore it is clarified that the lateral movement of the bend is reduced by proposed method.

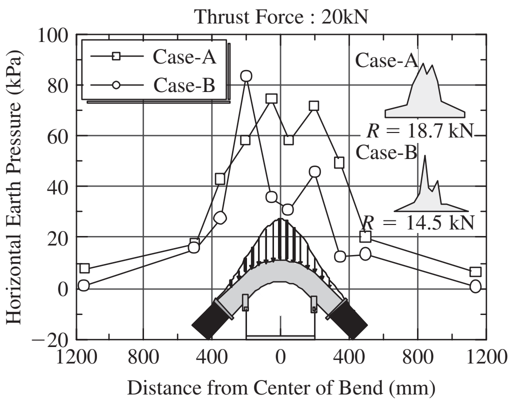

Figure 5. Distributions of earth pressure acting on bend.

3.2 *Earth pressure acting on pipe bend*

A passive earth pressure and an active earth pressure act on a bend when the bend is laterally moved due to thrust force. Commonly the active pressure can be neglected since it is extremely small. In this study, ten earth pressure cells were installed as shown in Fig. 1 in order to measure passive earth pressure acting on the bend. Note that eight earth pressure cells were placed in front of the bend and two pressure cells were placed in front of the straight short pipes.

The earth pressure distributions for thrust force of 20 kN are shown in Fig. 5. It is found that the passive earth pressure around the center of the bend is relatively large and the distribution is not uniform. This distribution is close to the results in 3 D finite element analyses presented by Fujita et al. (1994). However, in the current design (M.A.F.E, 1988), the earth pressure acting on the bend is assumed as a uniform distribution. Thus, it is thought that the further examinations are required to improve the design method.

In addition, from in Fig. 5, it is found that the resistance force calculated using the earth pressure distributions is 18.7 kN in Case-A and the value is close to the thrust force (20 kN). On the other hand, in Case-B, the resistance force is 14.5 kN and the value is smaller than that in Case-A. Therefore it can be considered that other factors (i.e. geogrid and anchor plate) contribute to the lateral resistance in Case-B.

3.3 *Strain distribution in geogrids*

Tensile strains are generated in geogrids when the bend subjected to thrust force is moved laterally. In Case-B, Case-C, Case-D and Case-E, strain gauges were equipped on geogrids in extensional and transverse direction respectively.

Fig. 6 shows tensile strain distributions in geogrids in extensional direction at the displacement of 7 mm.

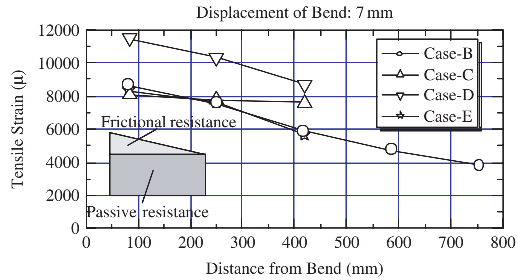

Figure 6. Tensile strain distributions in extensional direction.

These results are averaged in both side geogrids. From Fig. 6, it can be seen that the maximum strain is generated at the front position of geogrids and the minimum strain is generated at the end of geogrids. This behavior is similar to results of pull-out tests of geogrids in dry sand. However in general pull-out tests, tensile strain is not generated in the end of geogrids. These strain distributions are close to strain distributions in pull-out test under the condition, in which the end of geogrid was fixed (Nakamura, T. et al., 2003). It is thought that the end was fixed by the anchor plate in the proposed method. Therefore it can be understood that the tensile strain at the end of geogrid is generated due to the passive resistance acting on the anchor plate. Judging from these results, it can be assumed that tensile strain in geogrid is generated due to two components of pull-out resistance and passive resistance. The tensile strain from pull-out resistance is indicated with a triangle and the strain from passive resistance is constant and indicated with a rectangle.

Furthermore, from Fig. 6, it can be seen that the inclination of the strain distribution in Case-C is smaller than that in other cases. It can be considered that the pull-out resistance was small since the density of ground around geogrid was small. In addition, comparing Case-D and Case-E, the tensile strain in Case-E is smaller than that in Case-D. This result is considered to be due to difference of the installation of geogrids.

Fig. 7 shows tensile strains in geogrid in the transverse direction. Generally it is thought that strain at deep position is larger than that at shallow position since the horizontal earth pressure acting on geogrids increases with the depth. However, this tendency can not be seen in Fig. 7. For this reason, it can be considered that the height of geogrid was short (300 mm) and the variation of earth pressure in direction of depth was relatively small. Thus it is thought that variation of strain in vertical direction can be neglected in case of short geogrid in practical design.

Fig. 8 shows tensile strains in geogrid behind the plate in Case-E. From Fig. 8 it is found that tensile strains are approximately 2000 μ. It can be understood

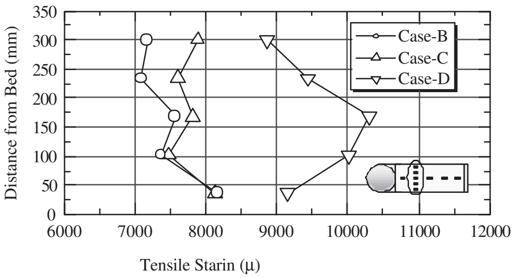

Figure 7. Tensile strain distributions in direction of depth.

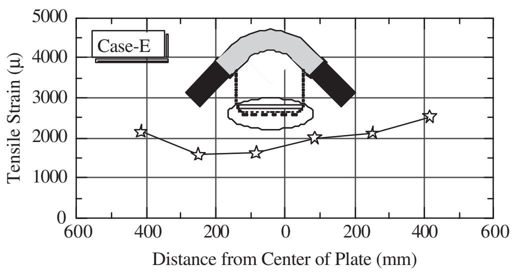

Figure 8. Tensile strain distribution behind anchor plate.

that, as shown in Fig. 6, strains in side geogrids is reduced due to the tensile strain behind the plate.

3.4 *Incremental resistance*

In case of the proposed method, it was clarified that geogrid and the anchor plate contributed to the lateral resistance as shown in Fig. 6. If the total resistance provided by the proposed method is defined as incremental resistance, it is equivalent to the tensile force in the front of geogrid. Thus, the incremental resistance can be estimated by multiplying the strains by the stiffness of geogrids per unit length. The stiffness of geogrids can be obtained in Fig. 2.

Fig. 9 shows variations of the incremental resistance with the horizontal displacement of the bend in Case-B, Case-C, Case-D and Case-E.

From Fig. 9, it is found that the increment resistance increases with the horizontal displacement. In addition, comparing 4 cases, it can be seen that the increment resistance in Case-D and Case-B is much larger than that in Case-C and Case-E. From this result, it can be consider that the most important factor for the incremental resistance is the stiffness of geogrid.

In addition, the incremental resistance in Case-B is as large as that in Case-C although these cases are different in the length of geogrids. As shown in Fig. 6, pull-out resistance in Case-B is larger than that in Case-D since the contact area between geogrid and ground is large. On the contrary, with respect to the

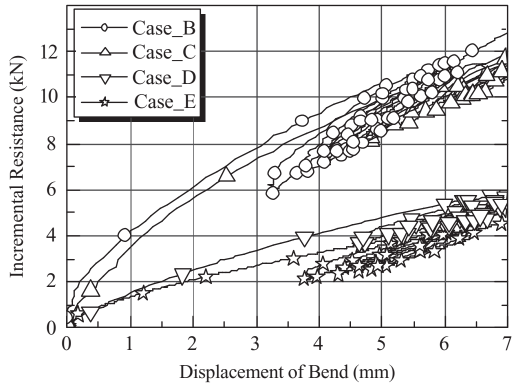

Figure 9. Relationships between displacement of bend and incremental resistance.

passive resistance acting on the anchor plate, Case-B is smaller than Case-C since geogrid is long and it is easy to be deformed. Therefore it can be thought that there is an optimum length of geogrid for the maximum resistance.

Further, it is found that the incremental resistance in Case-E is the smallest of all cases. The result indicates that passive resistance was slight since geogrid behind the anchor plate was elongated as shown in Fig. 8.

From the above discussion, important proposals on the stiffness and the length of and the installation of geogrids are found. I) The large incremental resistance can be expected in case of high stiffness geogrids since the large passive resistance is provided by the anchor plate. II) The large pull-out resistance can be expected in case of long geogrids. However the passive resistance acting on the anchor plate can be reduced in some degree. Therefore it is important to determine the optimum length of geogrids. III) In case of setting of geogrid as Case-E, the incremental resistance can be reduced due to the elongation of geogrid behind the anchor plate.

4 CONCLUSIONS

In this paper, large-scale tests for a buried pipe bend under internal water pressure were conducted in order to clear an effect of a proposed thrust restraint using geogrids and an anchor plate. Results in these tests are summarized as described below.

1. Horizontal displacement of the pipe bend was reduced in case of proposed method. Therefore the effect of proposed method was verified at actual size.
2. Tensile strain distributions along geogrids in extensional and transverse direction were discussed. As the results, it was found that the strain distribution

was the trapezium shape. In addition, the triangle part and the rectangle part were corresponding to the tensile strain from the pull-out resistance along the geogrids and the passive resistance acting on the anchor plate respectively. Furthermore it was cleared that the variation of strain distribution in vertical direction was slight and in case of small diameter bends, this variation can be ignored.

3. Incremental resistance due to geogrids and an anchor plate was calculated from results of tensile strains. As the results, it was found that the most effective factor for the lateral resistance was the stiffness of geogrid. In addition, it was indicated that there was the optimum length of geogrid for maximum lateral resistance. Therefore it is important for detail design to determine the optimum length of geogrid. Furthermore it was clarified that the incremental resistance was reduced due to the elongation of geogrid behind the plate in case of setting geogrid as wrapping the ground with the anchor plate.

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